Clinical Information Systems—A Review

BRUCE I. BLUM, *Laurel, Maryland*

Two hypotheses are offered in this review of clinical information systems: that the technology is mature, and that benefits to patient care can be shown. More than ten years of operational experience exist with each general class of clinical information systems, and these systems favorably affect staff, reduce errors, improve accessibility to medical information and provide alerts and reminders. To reinforce the maturity hypothesis, most cited studies are also a decade old. Clinically oriented systems are practical and can improve the health care process—a key goal in this era of prepaid or prospective payment for services.

(Blum BI: Clinical information systems—A review, *In* Medical informatics [Special Issue]. West J Med 1986 Dec; 145:791-797)

Clinical information systems are defined as computer-supported applications with a relatively large and long-term data base containing clinical data that are used to assist in the management of patient care. Most hospital information systems are clinical information systems by this definition. Examples of systems that are not include a hospital billing system (no clinical data), a physiological monitoring system (no long-term data base) and a registry or research data-base system (not used in patient care). The technology for these systems is mature and their benefits have been shown.[1,2] Consequently, one should expect to find more widespread use of these systems in the coming decades.

As the name implies, a clinical information system is an application of information system technology. Like every tool-based product, the power of the clinical information system has been limited by the resources of the equipment available to support it. Consequently, in the early days of computing, clinical information system applications were speculative and experimental. In the late 1960s, large disk memories, data-base management systems and lower cost minicomputers made it possible to develop and evaluate operational systems. In the present period of relatively inexpensive equipment and widespread computer literacy, we are witnessing the general use of information systems in both clinical and health-administration applications.

The status of the clinical information systems is best understood when seen in the context of the medical informatics applications. We begin by identifying the types of objects processed:

- *Data.* These are the uninterpreted items given to an analyst or problem solver, such as the signals processed by an electrocardiograph or an imaging device.
- *Information.* This is a collection of data elements organized (or interpreted) to convey meaning to the user, such as an automated medical record or a flow sheet.
- *Knowledge.* This is the formalization of the relationships, experience, rules and so forth by which information is formed from data, such as signal-processing algorithms and the knowledge bases of expert systems.

This categorization of processed objects is artificial; there are no clear boundaries among the three. Nevertheless, there is a progression in complexity from data to information to knowledge.

Because of this increase in complexity, the first applications addressed only the least complex objects. We began with data processing, and now we are experimenting with the processing of knowledge. This is shown in Figure 1, which characterizes the applications by type and decade. It should be noted that there is a progression from concept to research to prototypes and, finally, to mature products. We have the greatest experience with data processing, which is now in its second generation of advanced development and is firmly rooted in the domain of biomedical engineering. Information applications went through a prototype period in the 1970s and are now mature. Finally, prototypes of the knowledge applications—decision making, expert systems and intelligent systems—are currently being evaluated in clinical settings.

While emphasis on knowledge processing is growing, the dividing lines between traditional information and knowledge-based paradigms—that is, data-base technology and artificial intelligence—are blurring. As will be pointed out, many clinical information systems rely on the application of medical knowledge. Moreover, one can expect this orientation toward integrating these paradigms to continue.

From The Johns Hopkins University Applied Physics Laboratory, Laurel, Maryland.
Reprint requests to Bruce I. Blum, The Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20707.

ABBREVIATIONS USED IN TEXT

AAMRS = automated ambulatory medical record system
COSTAR = Computer Stored Ambulatory Record System
HIS = hospital information system
OCIS = [The Johns Hopkins University] Oncology Clinical Information System
RMRS = Reigenstrief Medical Record System
SMAC = Sequential Multiple Analysis-plus Computer
TMIS = Technicon Medical Information System
TMR = The Medical Record

System Models

There are two basic models for clinical information systems. The first is for hospitals, where the assumption is that there will be a limited number of patients, each treated for a relatively long period of time and each requiring a great deal of clinical information related to the current admission. The facility is large, has a number of separate departments and requires a large staff. In addition to the functions of health care delivery, there are also hotel functions, business-office functions, personnel functions and the like.

The second system model is for ambulatory care settings, such as health maintenance organizations and office practices. In these settings there are more patients, a need for long-term follow-up, relatively short-term episodes of illness with limited clinical data for each episode and few functions not directly associated with the provision of health care. Unlike the hospital setting in which the charge for the record-keeping function is small when compared with the other costs of care, information-processing costs in an ambulatory care facility are highly visible.

Applications	1950s	1960s	1970s	1980s
Data	Research	Prototypes	Mature	Refinement
Information	Concepts	Research	Prototypes	Mature
Knowledge	Concepts	Concepts	Research	Prototypes

Figure 1.—Scope of medical computing.

Consequently, the two general types of clinical information systems are very different in character. The early hospital information systems (HISs) were targeted to reduce labor costs. It had been shown that approximately a fourth of the labor cost in a hospital was associated with information processing.[3] It was speculated, therefore, that if some of this processing could be automated, labor costs could be reduced. Thus, the basic HIS model became one of linking the various users of information to reduce redundancy and improve transmission. As will be shown in the following section, this approach had only a limited impact on labor costs. But it did reduce errors, speed communication and facilitate medical decision making.

Figure 2 shows a block diagram of an HIS, emphasizing its communication role. At the center of the system is the nursing unit where all patient care is coordinated. Administrative and business functions are shown to the left, ancillary services to the right. Each is viewed as a "source" or "sink" for patient data in this diagram. Each hospital department, however, could redraw this diagram to make its functions the key operation. For example, the pharmacy's view of an HIS is that it is a collection of programs that supports the operation of the pharmacy: maintaining profiles, printing work lists, producing labels, reporting activities and recording charges. To the pharmacy, drug orders are inputs to be processed and the drug profile is part of their data base. To nursing stations, on the other hand, the order is a request for drugs and the profile is part of the medical record. Thus, an HIS is a large and complex system that must support many users with different perspectives. That is why it typically takes from six months to two years to install—even when no programming is required.

An ambulatory care system is considerably less complex. Figure 3 shows a model for the flow within an automated ambulatory medical record system (AAMRS). The central event is the encounter (patient visit). Some form of medical record must be available to the provider (physician) before the encounter. In situations where a patient comes by appoint-

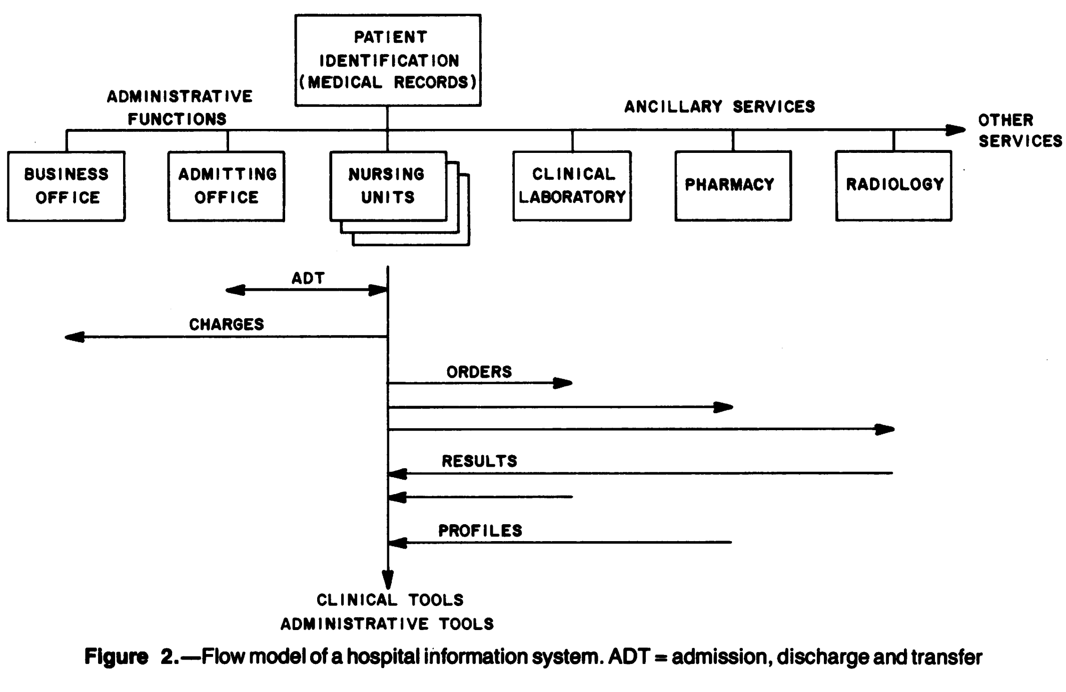

Figure 2.—Flow model of a hospital information system. ADT = admission, discharge and transfer

ment, an encounter form will be printed before the appointment date. The encounter form (for an AAMRS) typically contains some extract of the automated medical record plus space to record information derived from the current visit. The form normally serves as the permanent medical record, a data-entry form for the automated ambulatory medical record and a form for ordering follow-up actions and tests. In situations where a patient has no appointment, the encounter form may be printed on demand.

Within these two general models there are many variations. The orientation of the system may be to support administrative functions; the use of the system for patient care is seen, therefore, as fortuitousness. Conversely, the goal of the system may have been to support the patient care process. Systems with this objective also will be able by necessity to support almost all of the administrative and business functions; they must know where a patient is, what tests were ordered and drugs prescribed, what appointments have been made and kept and so forth. As a generalization, we note that systems designed for administrative purposes have difficulty adding clinical functions, but the reverse is not the case.

A second variation in clinical information systems is their scope of coverage. This is most pronounced in an HIS. In some cases, the HIS is limited to the basic admission, discharge and transfer functions plus one or more ancillary services. That is, the implementation approach is evolutionary: develop tools for one or more departments, learn from this

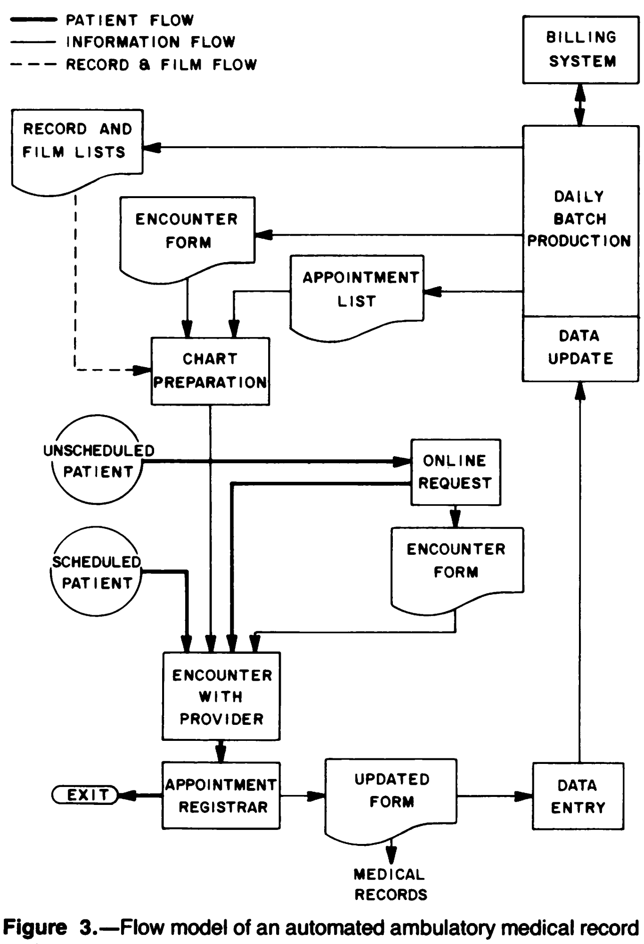

Figure 3.—Flow model of an automated ambulatory medical record system.

experience and add another department. With the growing availability of local area networks and stand-alone ancillary systems, there is a renewed interest in this approach. The alternative method—the holistic approach—seeks to implement all functions at one time. Because the risk generally is low and inasmuch as communication benefits increase with the number of communicating functions, there are many reasons to select this implementation path.

Some Hospital Information Systems

The following are HISs that have played an important role during the prototype evaluation period of the 1970s:

- The Technicon Medical Information System (TMIS) was installed at El Camino Hospital (Columbus, Ohio). It is one of the first HISs to be installed and was the subject of several major studies regarding the impact of an HIS.[4,5] The TMIS is an example of a holistic system designed primarily for administrative support. It has been in continuous use for more than 15 years and has been installed in 50 hospitals.
- The Problem Oriented Medical Information System, implemented by Weed and colleagues at the University of Vermont (Burlington), provides a completely automated medical record using a problem-oriented structure. The frames used by a provider represented a structuring of medical knowledge and a framework for organizing care.[6] This example of a care-oriented, holistic system is no longer in use at its prototype site; a commercial adaptation is available.
- The HELP system, developed by Warner and associates at the Latter-Day Saints Hospital in Salt Lake City, grew out of research in the early 1960s regarding the use of computers in patient care. The system was first implemented in intensive care units and then expanded to the rest of the hospital and its ancillary units. Medical knowledge is formalized as "HELP sectors," and the screening of all orders is invoked automatically. This is an example of a holistic HIS, designed to aid in patient care, that integrates both information and knowledge processing.[7,8] The system has been in continuous operation since the mid-1970s, and a commercial version is being evaluated.
- The Johns Hopkins University Oncology Clinical Information System (OCIS) was implemented by Lenhard and Blum and associates for a comprehensive cancer center. Although this is not a hospital information system, it is an example of how an information system can support patient care in a tertiary care setting. This system integrates inpatient and outpatient data, produces protocol-directed care plans for all inpatients and supports specialized functions such as blood product management and human leukocyte antigen type matching. It was implemented using only patient care resources and has been in continuous operation since the late 1970s.[9,10] Portions of the system have been transported to other centers.

This list of HISs emphasizes systems that have in some way contributed to our knowledge of clinical information systems. Naturally, there are commercial systems that use the results of the research and development characterized by the examples in this list. All of these systems—except the last—were recipients of significant external support. Thus, they were viewed, in part, as research activities. The OCIS, however, was started in 1975 and has been supported entirely by patient care funds. This may be taken as a sign of the field's maturity: by the mid-1970s the available experience and technology suggested that the cost of a system could be justified solely on the basis of the anticipated benefits. Yet, readers should not be misled by the bias of this list; most HISs are implemented for administrative gains and cost reduction; few have a medical decision-making orientation.

Some Ambulatory Care Systems

Two events help in the cataloguing of AAMRSs. The first is a 1975 state-of-the-art survey conducted by Henley and Wiederhold in which they identified 200 potential systems.[11] On further examination, many of these were found to be no longer operating. From this list, 17 systems were selected for more detailed study. By the time the report was issued, one of these was also no longer in existence. The second event was a follow-up to this study in 1981.[12] Although most of the initial systems were still operating, in all but three cases their role in clinical care had remained the same or had contracted. The three clinically oriented systems reported on are as follows:

- Computer Stored Ambulatory Record System (COSTAR), developed by Barnett and co-workers at Harvard University, supports a completely automated medical record. Initially designed for a health maintenance organization, the system was rewritten in the late 1970s as a public domain version (COSTAR V), and assistance was given to small companies to integrate and maintain support to health care organizations. The system provides a billing system, appointment system and query functions as well as an automated medical record.[13,14] There are many COSTAR implementations throughout the world in facilities ranging in size from a hospital to a private practice.
- Regenstrief Medical Record System (RMRS), implemented by McDonald and co-workers at the University of Indiana (Indianapolis), was one of the first to build a medical knowledge base to produce reminders regarding therapy and tests. In preparation for each encounter, its knowledge is queried and the encounter form is modified to collect data appropriate to each specific patient; a list of reminders is also printed.[15,16] The system has been successfully transported to other facilities.
- The Medical Record (TMR) was developed by Hammond, Stead and their associates at Duke University (Durham, NC). TMR is an outgrowth of earlier work and is intended to provide a set of integrated tools flexible enough to meet the needs of both an office practice and a research institution.[17,18] The system is in use in practices throughout the country.

As in the list of HISs, this list of AAMRSs is short and biased by an interest in research rather than commercialization. Clearly there are more clinical information systems designed for ambulatory care settings; there are even more systems that provide only administrative support. Yet, as the two AAMRS studies suggest, a discouragingly small portion of the systems is designed to assist in patient care.

Maturity of the Technology

In the opening paragraph of this paper, my theses were stated: clinical information systems are mature and their benefits have been demonstrated. In this section we have identified systems that have been in operation for ten or more years—a clear demonstration of the technology's maturity. In the following section, the impact of these systems on health care will be examined.

Evaluation

The evaluation of a health care system generally is presented in terms of its structure, process or outcome benefits and its effect on costs. In the case of computer technology, it is also possible to view the impact of a system in terms of its enabling benefit—that is, the availability of the system enables an organization to carry out activities that would not otherwise be possible. The most dramatic illustration of this was seen in clinical laboratories when automated analyzers were introduced. For example, the Mount Sinai Hospital in New York did 260,000 tests in the entire year of 1965; once a Sequential Multiple Analysis-plus Computer (SMAC) was installed, the chemistry department was doing 8,000 to 10,000 tests per day.[19] This ability of a laboratory to do more tests, at a lower cost per test, with more rapid reporting removed some constraints on test ordering.

In the clinical laboratory, the use of computers enabled clinicians to order tests as necessary. In effect, the computer allowed clinicians to use familiar tools and techniques while suppressing the limitations of scale. That is, the computer system facilitated operations that would not be practical using manual methods. This is quite different from the contribution of the new imaging tools that began with computed tomography. In this case, a new technology was introduced, alternative diagnostic methods became available and the domains of efficacy could be established.

With clinical information systems, a great deal of the benefit comes from their enabling power. Reliance on the new tools tends to be gradual, the changes (and benefits) are perceived as minor and (often) the system is appreciated only during periods of failure. Thus, the benefits of clinical information systems are difficult to identify and evaluate. In many cases, their availability has led to the assumption of obligations that might not otherwise have been accepted. For example, the power of the HIS business systems has allowed hospitals to respond to complex external reporting requirements. These requirements were not design goals for the system; rather they were obligations appended after the ability to meet these needs was available. Thus, the HIS business system enabled expanded reporting. As will be shown in the next section, clinical information systems produce improvements in health care. Given their enabling power, if the resources are managed properly, then one should expect even more widespread clinical benefits to materialize.

Benefits

The benefits of a health care system are normally distributed among three categories:

- *Structure.*—The capacity of the facilities and the capacity and qualification of the personnel and organization.
- *Process.*—The changes in the volume, cost and appropriateness of activities.
- *Outcome.*—The change in health care status attributed to the object being evaluated.

What we have termed enabling effects are generally considered structural benefits. Most of the measurable effects of information systems, however, are seen as changes in the process. It is assumed that the changes in process will improve the health care status, but to date there are no studies that clearly show an outcome benefit. In what follows, we summarize the results of some of the earlier studies relating to the process benefits. Note that most of these results have been available for a decade.

Impact on staff. The studies on the impact on staff may be divided into two categories. The first involves early implementations during a period when the use of interactive computing was relatively rare. The second involves studies during the current period of general computer familiarity. In the case of the TMIS at the El Camino Hospital, a mid-1970s study showed that nursing acceptance was always high.[20] In June 1974, 92% of the nurses favored the system. In part this reflected the fact that with fewer clerical requirements, more nursing hours became available for patient care. Similar acceptance of the HIS was found in the ancillary service departments. For these reasons, the availability of an HIS now is seen as an advantage in recruiting staff.

Acceptance by physicians has always been less enthusiastic. In the June 1974 El Camino Hospital survey, only 61% of the physicians voted to retain or extend the systems, and some of these still expressed negative opinions. In part, this limited acceptance stems from the facts that the system does not satisfy existing physician needs, their use may seem awkward,[21] the use of the technology may seem foreign to established physicians[22] and the acceptance of enabling technology occurs gradually over time. These issues of adaptation, diffusion and utilization are being restudied with the current generation of systems.[23] Acceptance of and familiarity with the technology seem to go hand in hand. Also, there is a tendency to accept a tool more readily when the user has participated in its design.[12]

Access to medical information. Because all clinical information systems maintain some form of patient record, they also will have some effect on the availability and structure of the medical record. In an HIS that contains subsystems for the ancillary services, for example, there will be more rapid reporting of results. As soon as a result is available, it is available to all authorized users. In addition to the advantages of more timely reporting, there also is the ability to organize the information to meet special needs. TMIS, like most HISs, allows analysts to structure the information produced—outputs—for use by different classes of user or department. COSTAR has specialized reports for pediatric, hypertensive and other patient categories. RMRS modifies the flow sheets and encounter forms to fit the patient problem list and OCIS routinely plots patient functions according to physician-established formats for disease and therapy combinations. Thus, the medical record is viewed as a ubiquitous, dynamic source of information rather than a physical sequential document.

The fact that medical records may be referenced concurrently from many different locations improves their availability. Records no longer are "lost"—a major impediment to care in situations where there can be emergency admissions (such as at an oncology center) or unscheduled visits (an emergency room). For example, the "core" record was designed for outpatient departments in a large teaching hospital where locating the paper record was not always easy. One short evaluation of an earlier version of the system found that 17% of the patients in a medical clinic had no charts available on the day before an appointment and 10% had no charts available at the time of a visit. In contrast, 95% of all patients had a printed automated record in time for a visit.[24] Similar results have been reported elsewhere.

Given the fact that an automated record can always be found, the next question is to determine what information is actually used. In one interesting study in an ambulatory care setting, providers were divided into two groups. The first group received a manually maintained flow sheet plus the complete record; the second group received only the flow sheet but was allowed to request the chart as well. At the end of each encounter, a physician reviewed all charts for overlooked clinical information. In all, 59% of the study group physicians (flow sheet only) chose not to receive the full record. Moreover, the study group was found not to differ from the control group with regard to following up clinical information as measured by the chart reviews before and after patient visits. The investigators concluded "that a flow-sheet type of summary medical record can serve as the sole source of clinical information in a substantial number of outpatient follow-up encounters in a medical subspecialty clinic without deterioration in the communication of clinical information."[25]

Thus, it is clear that the availability of automated records enables information that contributes most to the decision-making process to be extracted and formatted. Such formats should improve the recognition of trends, reduce information overload and foster better patient care.

Reduction in errors. Computer-stored medical data should be freer from errors than the traditional manually recorded record. A computer can be programmed to reject unreasonable values, integrating information reduces transcription errors and the ability to present the same datum in a variety of contexts facilitates the recognition of erroneous values. This has been confirmed in many studies. It will suffice to report on the mid-1970s work of Simborg and co-workers.

In a ward-management system that processed orders, Simborg and colleagues compared automated and unautomated units and found that with automation transcription errors were reduced (1.7% for the automated unit as compared with 7.3% for the control). They also recorded a lower rate for failure to carry out an order exactly (5.8% versus 14.7%).[26] Comparing an automated unit dose and unautomated bulk-distribution pharmacy system showed similar results. Errors of commission in the manual system were 4.6 times more frequent.[27] Although the technology used for these early systems has rendered them obsolete, they represent some of the earliest demonstrations of the ability of an HIS to reduce errors.

Surveillance and reminders. If the mere use of a clinical information system to store and display patient data facilitates understanding and reduces errors, then what can be accomplished if the processing is augmented by the application of medical knowledge?* First, knowledge may be applied in one of several basic ways. All actions may be evaluated against some knowledge base so that alerts can be issued if potentially dangerous patterns are identified. Most drug-drug interaction facilities operate in this way. Second, the knowledge may be used to suggest therapies or tests based on standard treatment algorithms and patient status. Reminder and protocol-di-

*We use the term medical knowledge in its generic sense as opposed to implying that it is structured as a knowledge base to be accessed by an artificial intelligence application.

rected care applications are examples of this mode. Finally, a third mode of application is consulting a system for expert advice or critiquing—most artificial intelligence systems fall into this category.[28]

By way of an example of the surveillance approach, the HELP system maintains medical knowledge and examines all orders with respect to these established criteria. In a 1976 report it was shown that of more than 13,000 patients monitored, 5% of the patients' pharmacy orders indicated some form of drug-drug interaction and initiated an alert, and 77% of these alerts resulted in changes in orders.[29] A more recent study at Latter-Day Saints Hospital (1981 to 1982) found that 1.8% of patients generated a pharmacy alert that was considered life-threatening and that there was a 94% physician compliance to the life-threatening alerts.[10]

RMRS, as previously noted, produces reminders for each visit. McDonald has studied the impact of these reminders on physician behavior. The first of these studies was published in 1976.[30] Because RMRS maintained a complete data base, it was possible to identify what actions were taken during an encounter, such as ordering a test or prescribing a medication. Thus, there was an environment to determine if the actions of a clinician differed when reminders were presented. Over a period of eight months, some 600 patient visits were assigned to a control and a study group. Only the study group received the reminders. For both groups, however, the reminder suggestions and the encounter actions were recorded. The results indicated that when reminders were present, there was a greater tendency to follow their advice. This was most dramatically noted in the case of clinically significant changes in therapeutics, where the responses were 47% with and 4% without computer assistance.

In this evaluation, the patients were assigned to the study or control group; few patients had the same provider in successive visits. McDonald next asked the question, What if there was continuity of care and the clinicians were assigned to study and control groups: could the reminder system be used as a "training" tool to "perfect" the physicians' performance? A crossover study was designed with two groups of physicians. One group spent seven weeks with the reminders and then nine weeks without them; the other group spent the first seven weeks without reminders and the final nine weeks with them. All groups using the reminders were asked to comment on them and indicate if they agreed or disagreed with the protocol or if there were insufficient data to determine if the protocol applied to a given patient. As in the previous study, the response to events was greater when reminders were present.

It was expected that the reminders might alter behavior. There was no difference, however, in the behavior of the two groups during the control period. That is, there was no residual change in performance (no training effect) for the group that initially used the reminders. Moreover, when one divided the physicians by level of training, one could find no significant overall effect on the results. This led McDonald to conclude that the problem was not one of training; rather, he said, "it is very likely that the physicians in these studies were simply unable to detect all the multitudinous conditions specified by the standards used."[31] He called this phenomenon information overload.

The ability to provide reminders or guidance also has been shown with other systems. COSTAR has been used to verify that follow-up actions have been taken in the event of a positive throat culture.[32] Wirtschafter and associates have shown how algorithms can be used to guide outreach physicians in administering cancer chemotherapy. In one study they reported that protocol compliance was 94% for the group using the system and only 64% for the nonuser group.[33] Thus, even before we begin to exploit the new tools that research in artificial intelligence is producing, there is ample evidence to suggest that we are barely taking advantage of the things that we already know how to do.

Costs. The initial goal of the HIS was to reduce labor and its associated costs. Clearly, equipment costs have fallen dramatically since the 1970s, and functions that were not cost effective at that time may be so today. Nevertheless, it is useful to stop and consider what is known about the effect of clinical information systems on cost.

In 1981 Drazen and Metzger reviewed ten cost studies of automated hospital information systems and reported the following conclusions[34]:

- Few rigorous studies have been conducted of the cost effects of implementing automated hospital information systems.
- Most of the work done in this area in the past has involved predicting cost impacts. Somewhat overstated cost savings—largely the result of unrealistic labor savings and the inclusion of revenue effects—and understated system costs may have produced unrealistic estimates of the net cost impacts of an automated HIS.
- Little work has been done validating the results of predictive methods. Therefore, there is very little documentation of the actual impact of an automated HIS on the productivity of hospital staff or on overall changes to guide the conduct of cost assessments.
- Through improvements in information flow, an automated HIS offers benefits to the quality of service, and these are usually major motivations for a hospital to implement a system. More exploration needs to be done of the cost implications of improvements in the quality of service, such as improved turnaround time for test results reporting and a decreased loss of information.
- Revenue recovery for charge capture is not a measure of changes in the cost of operating a hospital and, therefore, should not be counted among the cost effects.
- Cost studies have been conducted for different hospital settings and system configurations. The specific methods used are generally applicable, however, to any setting or system type. The purpose in undertaking the cost study determines the approach that is used.

As these conclusions suggest, most cost studies are prepared to justify a purchase and are never evaluated. The reason for this is that evaluating an operational system is both difficult and expensive. For example, consider the experience of the El Camino HIS evaluation. Work began in the early 1970s, the data were collected in the mid-1970s and the last report was issued in 1980. Clearly, over this period of time there were many changes in the El Camino Hospital, the national health care system and computer technology. The conclusions of the final report were as follows:

> The results indicate that the system improved productivity in the medical care departments and caused an overall reduction in patient length-of-stay. From a

total hospital cost perspective, however, the results were not definitive. Under the assumption that support department cost increases that were found were not directly caused by TMIS, the system was estimated to be approximately 60 percent self-supporting in 1975.[20]

Read another way, this means that 40% of the system's operational cost produced the benefits cited in the first sentence.

Perhaps the proper conclusion to draw from our studies of the cost impact is that major reductions in operating costs do not seem to result from installing a clinical information system. The major gain is in the benefit to patient care and the enabling of new tools that improve care. In the previous era of cost reimbursement, savings in labor could be transferred to increased profits. But in an environment of prepaid health care and prospective payment for hospital admissions, improved health care becomes the avenue to profitability. And it is here that clinical information systems have shown their efficacy.

Summary

I began by stating a hypothesis that should now be accepted as valid: clinical information systems represent a mature technology of demonstrated benefit. When we consider how few systems have been deployed, however, we must wonder what is necessary for the successful transfer of this technology. I propose the following areas for further activity:

- Education is required so that clinical users will understand what already is known. This will enable them to build on the state of the art rather than to reimplement it. It also will produce a demand for more sophisticated products that should act as an incentive to commercial vendors. Fortunately, a new generation of texts is available to aid in this education process.[1,35]
- Research is necessary in two major areas. First, the impact of clinical information systems on the health care process must be evaluated. Some studies have been briefly examined here, but much folklore lingers. Second, the clinical information systems should be viewed as a data repository to be referenced by knowledge-oriented tools. This implies research topics in knowledge representation, communications, human factors and the like.
- Commercial products that take advantage of our deeper understanding are needed. There is a dilemma for commercial vendors. Users expect tested, robust systems, and this generally takes five years from concept to operation. On the other hand, users also want the latest features. This conflicts with the economics of development. If the marketplace demand is sufficient, however, vendors may be encouraged to use the new generation of software tools to build knowledge-oriented systems.

By way of conclusion, I see the previous decade as one of discovery and validation. I would hope that the next will be characterized by the exploitation of previous developments and the integration of existing systems with medical knowledge and knowledge-based paradigms. If this occurs, then there is the possibility that clinical information systems will have an impact on health care delivery systems in the 1990s similar to that of the SMAC on the clinical laboratories in the 1960s or computed tomography on the diagnostic tools of the 1970s.

REFERENCES

1. Blum BI: Clinical Information Systems. New York, Springer-Verlag, 1986
2. Blum BI (Ed): Information Systems for Patient Care. New York, Springer-Verlag, 1984
3. Judstrup RA, Gross MJ: Cost of information handling in hospitals. Health Services Res 1986, Winter, pp 235-271
4. Battelle Memorial Institute: Evaluation of the Implementation of a Medical Information System in a General Community Hospital, Evaluation Studies and Analyses. National Technical Information Services (NTIS) publication No. 232 735, Sep 30, 1973
5. Barrett JP, Hersch PL, Caswell RJ: Evaluation of the Implementation of the Technicon Medical Information System at El Camino Hospital, part II, Economic Trend Analysis. Columbus, Ohio, Battelle, May 14, 1979
6. Weed LL and the PROMIS Laboratory: Representation of Medical Knowledge and PROMIS. Proceedings of the Second Annual Symposium on Computer Applications in Medical Care. Washington, DC, IEEE Computer Society Press, 1978, pp 368-400
7. Pryor TA, Gardner RM, Clayton PD, et al: The HELP system. J Med Syst 1983, 7:87-102
8. Warner HR: Computer-Assisted Medical Decision Making. New York, Academic Press, 1979
9. Lenhard RE Jr, Blum BI, Sunderland JM, et al: The Johns Hopkins Oncology Clinical Information System. J Med Syst 1983; 7:147-174
10. Blum BI, Lenhard RE Jr, McColligan EE: An integrated data model for patient care. IEEE Trans Biomed Eng 1985; 32:277-288
11. Henley R, Wiederhold G: An Analysis of Automated Ambulatory Medical Record Systems, Technical Report #13. San Francisco, Office of Medical Information Science, University of California, San Francisco, Medical Center. National Center for Health Services Research (NTIS), publication No. 254 234, Jun 1975
12. Kuhn IM, Wiederhold G, Rodnick, JE, et al: Automated Ambulatory Medical Record Systems in the United States, Technical Report STAN-/CS-82-928. Stanford, Calif, Stanford University, Aug 1982
13. Barnett GO, Justice NS, Somand AE, et al: COSTAR system, chap 19, *In* Blum BI (Ed): Clinical Information Systems. New York, Springer-Verlag, 1986
14. Barnett GO: The application of computer-based medical record systems in ambulatory practice. N Engl J Med 1984; 310:1643-1650
15. McDonald CJ: Data base management, feedback control, and the Reigenstrief medical record. J Med Syst 1983; 7:111-126
16. McDonald CJ: Action-Oriented Decisions in Ambulatory Medicine. Chicago, Year Book Medical, 1981
17. Hammond WE, Stead WW, Feagin SJ, et al: Data base management system for ambulatory care, chap 15, *In* Blum BI (Ed): Clinical Information Systems. New York, Springer-Verlag, 1986
18. Hammond WE, on Stead WW: A history of TMR, SCAMC-10, Proceedings of the 10th Annual Symposium on Computer Applications in Medical Care. Washington, DC, IEEE Computer Society Press, 1986
19. Bronzino JD: Computer Applications for Patient Care. Menlo Park, Calif, Addison-Wesley, 1982, p 120
20. Demonstration and Evaluation of a Total Hospital Information System, Dept of Health, Education and Welfare (DHEW) publication No. (HRA), 77-3188. Government Printing Office, Jul 1977
21. Stratmann WE: A Demonstration of PROMIS. DHEW publication No. (PHS) 79-3247. Government Printing Office, Sep 1974, pp 7-8
22. Anderson JG, Jay SJ: The diffusion of computer applications in medical systems. Med Inf (Lond) 1984; 9:251-254
23. Anderson JG, Jay SJ (Eds): Adoption, Diffusion, Utilization and Impact of Computers in Clinical Medicine. New York, Springer-Verlag, 1986
24. McColligan EE: Core record system, chap 18, *In* Blum BI (Ed): Clinical Information Systems. New York, Springer-Verlag, 1986
25. Whiting-O'Keefe QE, Simborg DW, Epstein WV: A controlled experiment to evaluate the use of a time-oriented summary medical record. Med Care 1980; 18:842-852
26. Simborg DW, MacDonald LK, Liebman JS, et al: Ward information-management system—An evaluation. Comput Biomed Res 1972; 6:484-497
27. Simborg DW, Derewicz HJ: A highly automated hospital medication system: Five years' experience in evaluation. Ann Intern Med 1975; 83:342-345
28. Blum BI: Artificial intelligence and medical informatics. Med Inf (Lond) 1986; 11:3-18
29. Halse RK, Clark SJ, Jackson JC, et al: Computerized medication monitoring systems. Am J Hosp Pharm 1976; 13:1061-1064
30. McDonald CJ: Use of a computer to detect and respond to clinical events: Its effect on clinical behavior. Ann Intern Med 1976; 84:162-167
31. McDonald CJ: Protocol-based computer reminders, the quality of care and the non-perfectability of man. N Engl J Med 1976; 295:1351-1355
32. Barnett GO, Winickoff RN, Dorsey JL, et al: Quality assurance through automated monitoring and concurrent feedback using a computer-based medical information system. Med Care 1978; 16:962-970
33. Wirtschafter DD, Scalise M, Henke C, et al: Do information systems improve the quality of clinical research? Results of a randomized trial in a cooperative multi-institutional cancer group. Comput Biomed Res 1981; 14:78-90
34. Drazen E, Metzger J: Methods for Evaluating Costs of Automated Hospital Information Systems. Dept Health and Human Services publication No. (PHS) 81-3283. Government Printing Office, Jul 1981
35. Shortliffe EH, Weiderhold G, Fagan L (Eds): An Introduction to Medical Information Science, 2 vol. Menlo Park, Calif, Addison-Wesley, in press